Direct Fuel Cell/Turbine Power Plant

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Objectives

- Conduct proof-of-of-concept tests of the DFC/T systems in sub-MW class power plant configuration.
- Develop the design of a 40 MW Direct Fuel Cell/ Turbine (DFC/T[a]) hybrid system with efficiencies approaching 75 percent (with natural gas), while producing sulfur and nitrogen oxide emissions of less than 0.01 lb/million BTU.
- Develop and evaluate the design of the key components including gas turbine, recuperators and high temperature catalytic oxidizer suitable for DFC/T systems.

Key Milestones

- Completed the design of a subscale hybrid system based on a 250-kW fuel cell stack and a 30-kW microturbine.
- Completed mechanical modifications of the 30-kW microturbine in collaboration with the microturbine manufacturer.
- Completed the construction of the subscale hybrid power plant.
- Developed and implemented the plant control system, including modifications to the microturbine control software and data communication hardware.
- Verified DFC/T concept in a sub-megawatt power plant.

Approach

FCE's Vision 21 project has been focused on the development and testing of critical components for the DFC/T hybrid power system. One of the project tasks involves integration of a 250 kW DFC stack with a micro-turbine. In this task, the issues related to the integration of a fuel cell with an indirectly heated Brayton cycle are being addressed. The sub-MW proof of concept DFC/T power plant was designed in FY 2000, followed by construction and testing in FY2001 - FY 2002. Figure 1 shows a simplified process flow sheet for the subMW DFC/T power plant.

The design activities included the development of process flow diagram, piping and instrumentation diagrams, process simulation, and procurement of the balance-of-plant equipment. One of the key areas of development was design modifications incorporated in a Capstone Simple Cycle Model 330 microturbine. The microturbine modifications included special casing design with provisions for flow of gases to and from balance-of-equipment heat exchangers.

The microturbine was constructed with a compressed air exhaust port and expander inlet pipe to provide flow connections to the fuel cell system. At the time of the power plant construction, the microturbines with adequate airflow for high power operation were still under development. An air blower was also included to supplement the microturbine airflow at high power operation. The air blower also increased the flexibility of operation for the testing purposes. The power plant was capable of operating in a dual mode: 1) fuel cell/turbine integrated mode, 2) fuel cell only mode. The dual mode capability was used to evaluate of the benefits of the DFC/T cycle over the fuel cell-only cycle.

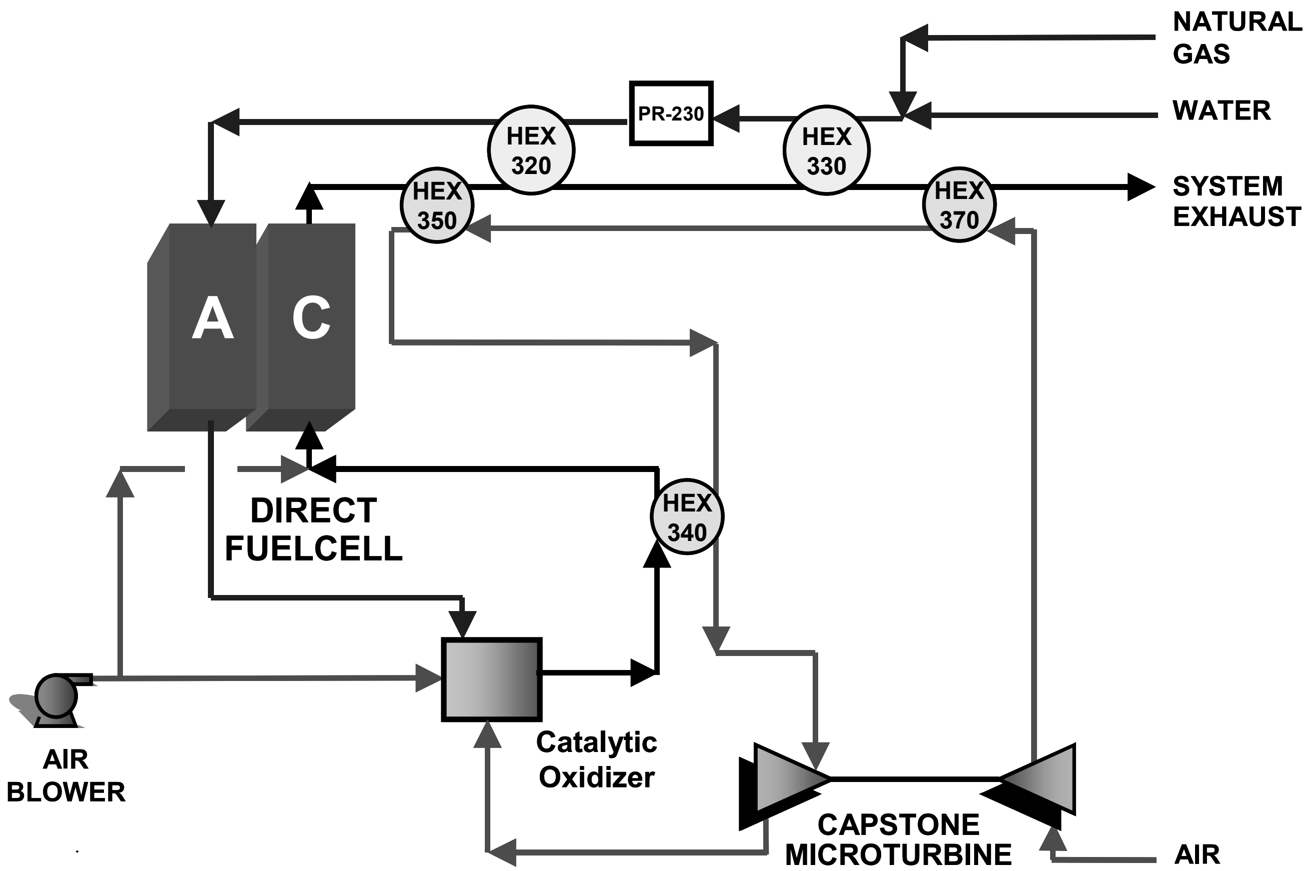

Figure 1. *SubMW DFC/T process flow sheet.*

The microturbine control software was modified to incorporate the power plant operational requirements based on the fuel cell airflow and microturbine speed relationship. The data communication hardware between the plant's supervisory control and the microturbine was also implemented.

The DFC/T system utilizes an indirectly heated Brayton cycle to supplement the fuel cell power. Various heat exchanger technologies were investigated during the design phase including: compact brazed plate-fin, shell-and-tube, and finned tube. The shell-and-tube heat recuperators were selected for implementation in the system.

Figure 2 shows a picture of the sub-MW hybrid power plant including a 250-kW fuel cell stack. The fuel cell stack was connected to a DC-to-AC inverter, independent of the microturbine high-speed generator. The inverter and the alternator were connected to the grid in parallel. This configuration allowed independent tests of the inverter and the generator during the unplanned grid failures (forced outages) and planned grid-disconnect tests.

Figure 2. *SubMW DFC/T® proof-of-concept power plant*

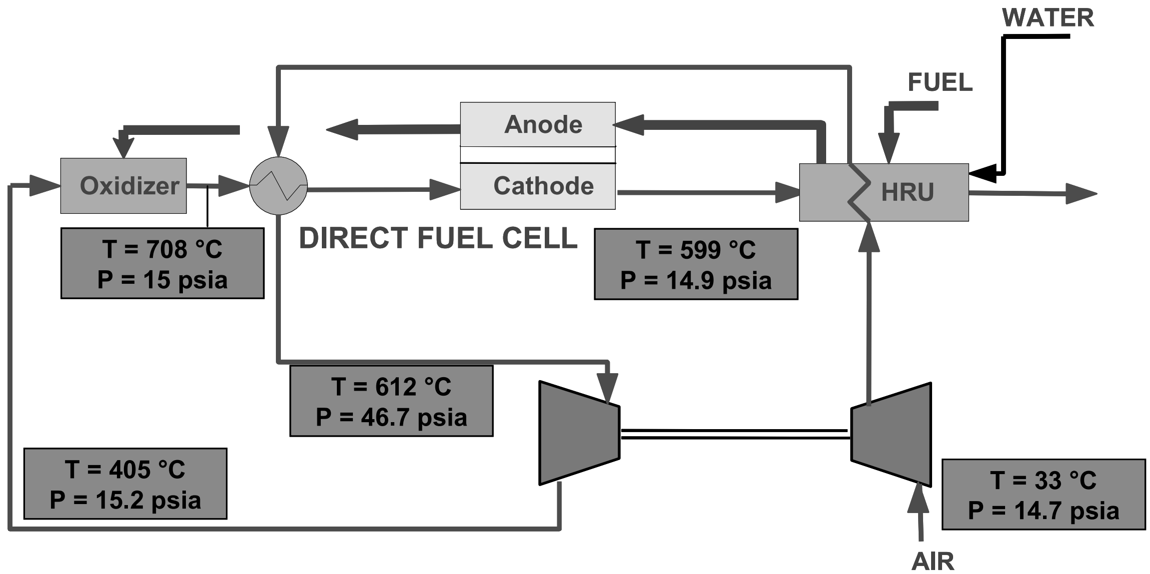

Figure 3. *Integrated DFC/T hybrid power plant test results.*

Results

The DFC/T power plant tests followed the installation and conditioning of a state-of-the-art DFC[â] stack. The microturbine integration tests were initiated in July 2001. To date, the R&D efforts have resulted in significant progress in validating the DFC/T cycle concept. Procedures were developed and implemented for start-up, power ramp (up and down), shutdown, and plant trip. The procedures were refined during the demonstration tests as the lessons learned. Computer simulation of the power plant including mass and energy balances was utilized as analytical tool during the testing period. The operational aspects of the hybrid system related to the integration of microturbine and heat exchangers with the fuel cell and process flow and thermal balances were investigated. Figure 3 shows typical operational test data for the DFC/T hybrid power plant mapped around the original system concept. The hybrid power system test results verified that efficiency gains are realizable by integration of gas turbine with the fuel cell.

One of the objectives of the demonstration was to develop the control logic for the operation of DFC/T. During the testing period, refinements in power plant control strategies were implemented. The control system modifications included thermal management of the stack and microturbine. The power plant emergency shutdown procedures resulting from grid failures and forced outages were tested successfully. Additionally, the demonstration tests provided valuable insight with respect to the potential for load following, increased reliability, and enhanced operability.

The balance-of-plant equipment and the microturbine performances were also monitored and evaluated during the course of the tests. The heat transfer coefficients for the heat exchangers were analyzed against the vendor supplied information. The power plant test facility had significant amount of the heat loss from the pipes and equipment. The shell-and-tube heat exchangers exhibited heat transfer coefficients in the order of 1 – 5 Btu/hr °F ft^2 for the gas-to-gas heat recuperation.

The microturbine airflow was not adequate for operation at high power densities. Supplementary air was required during the high power operation. The ambient air supplemented to the anode exhaust oxidizer resulted in lower than desired temperature at the gas turbine inlet. Tests were also conducted by augmentation of the low-Btu anode exhaust gas with natural gas in order to raise the turbine inlet temperature to 700 °C and to demonstrate a higher gas turbine power output.

Conclusions

Advances include proof-of-concept tests of a sub-MW class DFC/T power plant. The dual mode operation confirmed that greater efficiencies could be obtained by integration of a microturbine with the fuel cell. The efficiency gains in the DFC/T system are related to additional power produced from the gas turbine and reduction of auxiliary power consumption by the air blower. The test results have indicated that smaller sub-MW and MW-Class DFC/T hybrids are attractive for the distributed generation applications.

One key objective of the DFC/T demonstration was to obtain design information and operational data that will be utilized in the design of 40-MW high efficiency Vision 21 power plants. The results of the subMW system tests have indicated that effective recuperation of heat to the gas turbine and minimization of the heat loss from the balance-of-plant equipment are important factors in the design of DFC/T power plants. The combination of high heat losses and less than adequate heat transfer coefficient from the recuperators may limit the power from gas turbine in the hybrid power system. This effect is more enhanced at higher ambient temperature, due to sensitivity of the gas turbine electric output to the ambient temperature.

Another key objective of the hybrid power plant demonstrator was the development of control strategies including the fuel cell cathode temperature and the turbine inlet temperature. The power plant shutdown and emergency trip control logics were also developed. The control strategies developed and refined during the operation of the sub-MW power plant will be utilized in the development of piping and instrumentation diagrams for the larger 40-MW scale Vision 21 power plants.

The sub-MW power plant will be revamped with a Capstone Model C60 and a next generation of fuel cell stacks. The Model C60 is capable of providing the airflow for full load operation of the DFC stack. The implementation of higher flow also is expected to entail in additional gain in efficiency and increase in the power plant net output.

References

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